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§14. Conceptual Study on Internal Dump Methods for Superconducting Magnets with Conductive Sheets between Turns

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Fusion power plants must be operated in a steady mode, and their superconducting magnets should be operated under the constant currents. Therefore, it will be possible to replace turn-to-turn insulation by conductive sheets. Joule losses by the bypass currents in charging can be reduced within allowable level by slowing down the excitation rate. This concept can realize the internal-dump coil protection, which is called 'quench back'. When the excited magnet is opened to the power supply, the whole current flows the conductive sheets, and their joule losses heat up the whole magnet quickly and uniformly. Merits of this method are high reliability without outside protection circuits, low shut-off voltage, and needlessness of large-current conductors. Since the low voltage make it possible to use ceramic insulator between the layers, the radiation-resistance of the magnet can be improved.

The equivalent circuits for two layers are shown in Fig. 1. The joule loss in the conductive sheets in charging are given by

$$Q_{r2} = \frac{mn(L_1 mnI_1)^2}{R_2 t_1^2}, \qquad (1)$$

where L_1, m, n, I_1, R_2, and t_1 are the inductance per turn, the layer number, the turn number, the conductor current, resistance between turns, and charging time, respectively. The shut-off voltage is given by

$$V_{dump} = I_1 R_{dump} = (mnI_1)R_2. \qquad (2)$$

Design studies of a fusion magnet with the conductive sheets between turns are shown in Table I. The magnetic energy and magnet-motive force are set at 120 GJ and 50 MA, respectively. It shows that the resistance of tens of μΩ or more was necessary for the resistance between turns of the magnet to reduce the heat generation during the excitation within the conventional refrigerating power which must be less than 5% of the electric output. It means that the resistance only by stainless steels is too small for it. If the resistance is too large oppositely, the shut-off voltage exceeds the allowable value. Therefore, we need the conductive material that has 1,000 to 100,0000 times higher resistivity than stainless steels. As the results of survey of commercial materials, a few conductive ceramics and conductive resins were selected as candidates. The examples are Al_2O_3 with TiC, SiC, epoxy resins with conductive filler. Since their properties at low temperatures are not sufficient, further examination is necessary to select or develop the material for the conductive sheet.

A concept of a winding with conductive sheets between turns is shown in Fig. 2. The conductors are wound by double-pancake method. Rutherford cables of 20 kA class can be adopted even in such a large magnet by increasing the turn number. In order to realize the 'quench back', thermal conductance between the conductive sheets and the conductors should be good and uniform. From this viewpoint, glass tapes with conductive resins seem to be appropriate. Feasibility tests are planned.

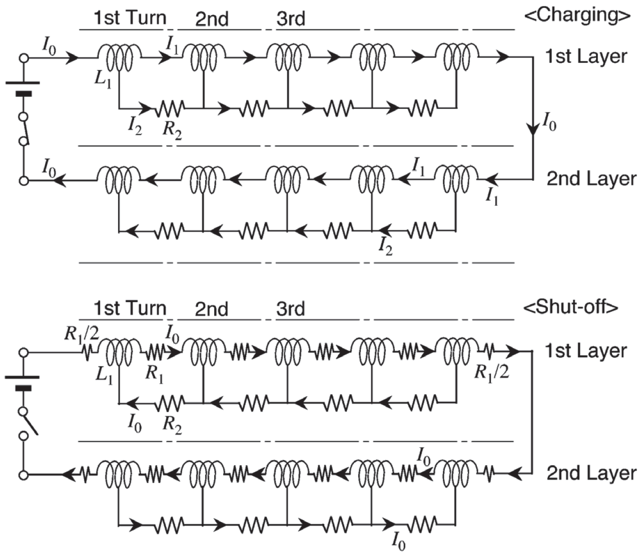

Fig. 1. An equivalent circuit of a magnet with conductive sheets between turns.

Table I. Major parameters of a fusion magnet with conductive sheets between turns.

Items (Unit)	Reactor (120 GJ, 50 MA)		
Layer * turn number	22*44	40*80	
Current (kA)	51.7	15.6	
Excitation time (hr)	120	120	
Thickness of material (mm)	0.205	0.225	
Resistance per turn (ohm)	0.000001	0.000002	(*1)
Excitation voltage/coil (V)	5.4	17.8	(*2)
Joule loss at charging (kW)	29.9	49.4	<50 kW
Initial shut-off time constant (hr)	12.91	21.33	at 4 K
Shut-off voltage (V)	50	100	<147 V

(*1) Resistivity of material (Al_2O_3+TiC): 0.03 ohm-m
(*2) Excitation time: 120 hr

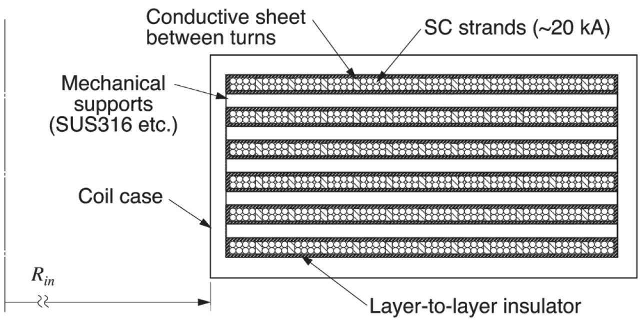

Fig. 2. Concept of a superconducting winding with conductive sheets between turns.

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